Application

for

United States Letters Patent

To all whom it may concern:

Be it known that

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have invented certain new and useful improvements in

IMPROVED EQUIVALENT CIRCUIT FOR DIELECTRIC CERAMIC FILTER

of which the following is a full, clear and exact description.

IMPROVED EQUIVALENT CIRCUIT FOR DIELECTRIC CERAMIC FILTER

FIELD OF THE INVENTION

This invention enables development and production of high electrical performance filters in sizes much smaller than what is capable with existing technologies, using an improved equivalent circuit.

BACKGROUND OF THE INVENTION

A ceramic body with a coaxial hole bored through its length forms a resonator that resonates at a specific frequency determined by the length of the hole and the effective dielectric constant of the ceramic material. The holes are typically circular, or elliptical. A dielectric ceramic filter is formed by combining multiple resonators. The holes in a filter must pass through the entire block, from the top surface to the bottom surface. This means that the depth of hole is the exact same length as the axial length of a filter. The axial length of a filter is set based on the desired frequency and available dielectric constant of the ceramic.

The ceramic block functions as a filter because the resonators are coupled inductively and/or capacitively between every two adjacent resonators. These components are formed by the electrode pattern which is designed on the top surface of the ceramic block couplings and plated with a conductive material such as silver or copper.

Ceramic filters are well known in the art and are generally described for example in U.S. Patent Nos. 4,692,726, 4,823,098, 4,879,533, 5,250,916 and 5,488,335, all of which are hereby incorporated by reference as if fully set forth herein.

With respect to its performance, it is known in the art that the band pass characteristics of a dielectric ceramic filter are sharpened as the number of holes bored in the ceramic block are increased. The number of holes required depends on the desirable attenuation properties of the filter. Typically a simplex filter requires at least two holes and a duplexer needs more than three holes. This is illustrated in Figure 9 where graph 10 represents the filter response with fewer holes than graphs 12 and 14. It is apparent that graph 14 which is the response of the filter with the most holes, is the sharpest of the three responses shown. Referring to Figure 10, it can be seen that the band pass characteristic of a particular dielectric ceramic filter is also sharpened with the use of trap holes bored into the ceramic block. Solid line graph 21 represents the response of a filter without a high end trap. Dashed line graph 23 represents the response of the same filter with a high end trap.

Trap holes, or traps as they are commonly referred to, are resonators which resonate at a frequency different from the primary filter holes, commonly referred to simply as holes. They are designed to resonate at undesirable frequencies. Thus, the holes transmit signals at desirable frequencies while the traps remove signals at the undesirable frequencies, whether low end or high end. In this manner the characteristic of the filter is defined, i.e. high pass, low pass, or band pass. The traps are spaced from holes a distance greater than the spacing between holes so as to avoid mutual interference between the holes and traps. As shown in Figure 11, whereas holes 31 are separated from each other a distance equal to D, a distance of 2D is placed between trap 33 and the transmission hole nearest to trap 33. The precise distance between trap and transmission pole is one of design choice for achieving a specified performance, but it is preferably 1 to 10 mm. Traditionally, the traps will be spaced from 1.5D to 2D from the holes.

Conventionally the holes 41 and traps 43 in a ceramic filter are positioned along a straight line. This design together with the spacing requirements addressed above limits the extent to which a filter may be reduced in size. Specifically, the performance characteristics of a given filter are a function of its width, length, number of holes and diameter of holes. The usual axial length L is 2 to 20 mm. The width w is determined by the number of holes. The usual width of the block filter is 2 to 70 mm. Reducing the number of holes, the diameter of the holes, or the spacing between holes, will effect the performance. Accordingly, it is desirable to have a design for a dielectric ceramic filter which can effectively reduce the size of a given filter while maintaining its given performance characteristics.

Equivalent circuits are generally those circuits with the same overall current, impedance, phase, and voltage relationships as a more-complicated counter part that it usually replaces.

There is a need for dielectric ceramic filters used in advanced communication applications such as CDMA and TDMA cellular phones with higher electrical performances and a smaller physical size. However the existing methods to develop a filter with higher electrical performance is to add additional transmission poles and/or trap resonators in a filter, which causes an increase in the size of the new filter.

SUMMARY OF THE INVENTION

This invention describes a new design for increasing the electrical performance without increasing the size of a high performance ceramic filter. To achieve this purpose, this invention describes a new equivalent circuit of dielectric ceramic filter with a new printed pattern on the filter to realize the new equivalent circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 depicts a typical equivalent circuit of a prior art filter.

Figure 2 illustrates the typical printed pattern of a prior art filter designed in accordance with the equivalent circuit of Figure 1.

Figure 3 illustrates the equivalent circuit for a filter designed in accordance with the present invention. This new equivalent circuit design has a similar electronic performance as the prior art filter of Figure 1, but is physically smaller.

Figures 4A-B illustrate one preferred embodiment of a printed pattern for a filter designed to perform as the equivalent circuit of Figure 3. C1 is the capacitance of coupling between input/output electrode and resonator θ1; C2 is the capacitance of coupling between θ1 and θ2; and C3 is the capacitance of coupling between input/output electrode and resonator θ2. Z is the inductance of coupling between θ1 and θ2. The shaded portion of the electric pattern, weakens C2. As a result of the weakened C2, Z is relatively strengthened.

Figure 5 compares the similarity in electrical performance between the filter designed in accordance with the present invention shown in Figure 3 and a prior art filter, such as shown in Figure 1. The rigid line is the electrical performance of the present invention shown in Figure 3 and the broken line is that of prior art filter shown in Figure 1.

Figure 6 illustrates the equivalent circuit for a duplexer designed in accordance with another embodiment of the present invention.

Figure 7A-B illustrates one preferred embodiment of a printed pattern for a duplexer designed to perform as the equivalent circuit of Figure 6. Figures 7C-D, 7E-G, 7G-H and Figures

7J-K and additional preferred embodiments and their equivalent circuits.

Figure 8 illustrates another preferred embodiment of a printed pattern for a filter designed to perform as the equivalent circuit of Figure 3. This filter has two (2) transmission poles and one (1) trap resonator, but it can work as a filter with three (3) transmission poles and one (1) trap resonator.

Figure 9 illustrates the increased sharpness of the band pass response of a dielectric ceramic filter as the number of holes in the filter increase.

Figure 10 illustrates the effectiveness of traps in removing high end frequencies.

Figure 11 is representative of the spacing between holes and hole and trap on a conventional ceramic block filter.

DETAILED DESCRIPTION OF THE INVENTION

One embodiment of this invention is a filter with 4 transmission poles and 2 trap resonators (total 6 holes), shown in Figures 4A-B. Capacitances C1, C2 and C3 are as shown in Figure 4B.

Resonator $\theta 1$ functions as a transmission pole by the coupling of Z1 and C2, so that $\theta 1$ can compose 5 transmission poles by cooperation with the other 4 transmission poles of $\theta 2$, $\theta 3$, $\theta 4$ and $\theta 5$. (See Figure 3)

Furthermore, $\theta 1$ also functions as a trap resonator by adjusting the coupling of C1, C2 and C3 as to be C1>C3>C2. Thus, $\theta 1$ can work as both a transmission pole and a trap resonator. Due to the unique pattern of the filter, $\theta 1$ can act as both a trap resonator and transmission pole, thus reducing filter size by eliminating one transmission pole. (See Figures 3 and 4A-B)

This means higher electrical performance can be achieved while having a smaller filter size by using this new design of equivalent circuit.

A new electrode pattern of conductive material was developed, as shown in Figs. 4A and 4B to realize the effect of the new equivalent circuit. Each value of W, L, X1 and Y1 in Fig.4A are the following ranges.

W: $0.5 \text{ mm} \geq W \geq 0.1 \text{ mm}$

L: $3.0 \text{ mm} \geq L \geq 0.5 \text{ mm}$

X1: $4.0 \text{ mm} \geq X1 \geq 1.0 \text{ mm}$

Y1: $2.0 \text{ mm} \geq Y1 \geq 0 \text{ mm}$

Fig. 4B shows parameters C1; C2 and C3. C1 is controlled by the distance between pattern 1 of conductive material for input/output electrode and pattern 3 of conductive electrode connected to conductive material on the inner surface of hole of $\theta 1$ resonator, and C3 is controlled by the distance between pattern 1 and pattern 4 of conductive material connected to conductive material on the inner surface of hole of $\theta 2$ resonator. C1, C2 and C3 are capacitances of coupling as described above in Figure 4B. Z is an inductive coupling and is controlled by the pattern 2 of conductive material that is opposed to the pattern 1 and is connected to the conductive material on the side wall. The relationship of C1, C2 and C3, to each other is as follows, C1>C3>C2.

Fig. 5 shows the electrical data of the filters developed by the existing technology and by our new technology along with the requested specification. Although the present invention's filter is smaller, due to the less amount of holes, than currently available filters, its performance matches the electrical performance of larger filters using presently available technology. The electrical

performance of the present invention (the filter of Figure 3) is represented by the rigid line as the shown in Figure 5. The electrical performance of a prior art filter (the filter of Figure 1) is represented by the broken line as shown in Figure 5.

We can also apply the concepts of this new filter technology to a duplexer. Figure 7 is a embodiment of a duplexer pattern of the present invention. Figure 6 is its equivalent circuit. Fig. 6 and Fig. 7A-K show examples of new equivalent circuits and printed patterns, as applied to a duplexer. The duplexer of Fig. 6 and 7A-B has eight (8) transmission poles and three (3) trap resonators, but it can work as a filter with nine (9) transmission poles and three (3) trap resonators. In most cases, the higher brand is the receiver band and the lower band is the transmitter band at the mobile phone terminal sides. These designations become reversed at the base station side. However, it is noted that the relationship of the receiver band and the transmitter band, on the one hand, and the higher/lower bands on the other hand are not always consistent.

The frequency of the off line hole at the center of the duplexer is nearly equal to that of higher band. In this case, higher band side is the right side of duplexer in Figure7. One embodiment of the duplexer filter has three input/output pads and three patterns of conductive material connected to those pads. The duplexer filter may or may not have trap holes at both sides of the filter.

Each value of W, L, X1 and Y1 for the duplexer filter are the following ranges.

W: $0.5 \text{ mm} \geq W \geq 0.1 \text{ mm}$

L: $3.0 \text{ mm} \geq L \geq 0.5 \text{ mm}$

X1: $4.0 \text{ mm} \geq X1 \geq 1.0 \text{ mm}$